The Geology of the Bungonia District, New South Wales

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Detailed geological mapping has provided stratigraphic and structural evidence for reinterpreting the geological history of the Bungonia area in the eastern Lachlan Fold Belt, New South Wales. The oldest rocks consist of a Late Ordovician distal flysch sequence (Tallong Beds) which shows isoclinal folding. The Tallong Beds are unconformably overlain by the Late Silurian shallow marine limestone — shale sequence of the Bungonia Limestone. Carbonate deposition ceased in the Late Silurian or Early Devonian when deposition of the Tangerang volcanics commenced. The latter sequence consists of lensoidal dacite flows interbedded with shallow marine volcaniclastic and tuffaceous sedimentary rocks. Emplacement of the southern part of the Marulan Batholith in the Early Devonian was probably coincident with a phase of broad folding. Erosional remnants of Permian and post-Permian sedimentary and volcanic rocks overlie parts of the older sequence.

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INTRODUCTION

The area mapped at Bungonia (Fig. 1) abuts the western margin of the southern Sydney Basin and includes a sequence of Ordovician to Devonian sedimentary and volcanic rocks. This sequence occurs in the eastern part of the Lachlan Fold Belt and has been intruded by the Marulan Batholith. Erosional remnants of younger sedimentary and volcanic rocks overlie part of the area.

The first detailed geological study of the Bungonia area was carried out by Woolnough (1909) and further references to the regional geology were made by Naylor (1935, 1936, 1939, 1950) and Garretty (1937). Aspects of the limestones were studied by Carne and Jones (1919), Pratt (1964), Ellis *et al.* (1972) and Pickett (1972), and descriptions of the Marulan Batholith were published by Osborne (1931, 1949) and Osborne and Lovering (1953). The district has been the subject of several unpublished honours theses.

The aim of the present study was to remap the area from Bungonia Gorge to Inverary Park (Fig. 1) to elucidate the stratigraphy, structure and tectonic development of the region.

TALLONG BEDS

Distribution and Petrography. The Ordovician Tallong Beds (Wass and Gould, 1969) are well exposed along the Shoalhaven River between Tallong and Bungonia, and form part of a much larger meridional belt of Ordovician rocks extending southwards to the coast between Bermagui and Tathra (Packham, 1969; Crook *et al.*, 1973).

In the Bungonia area, the Tallong Beds consist of micaceous, fine-grained, quartz-rich sandstone with shale, slate, siltstone, phyllite and chert interbeds (Table

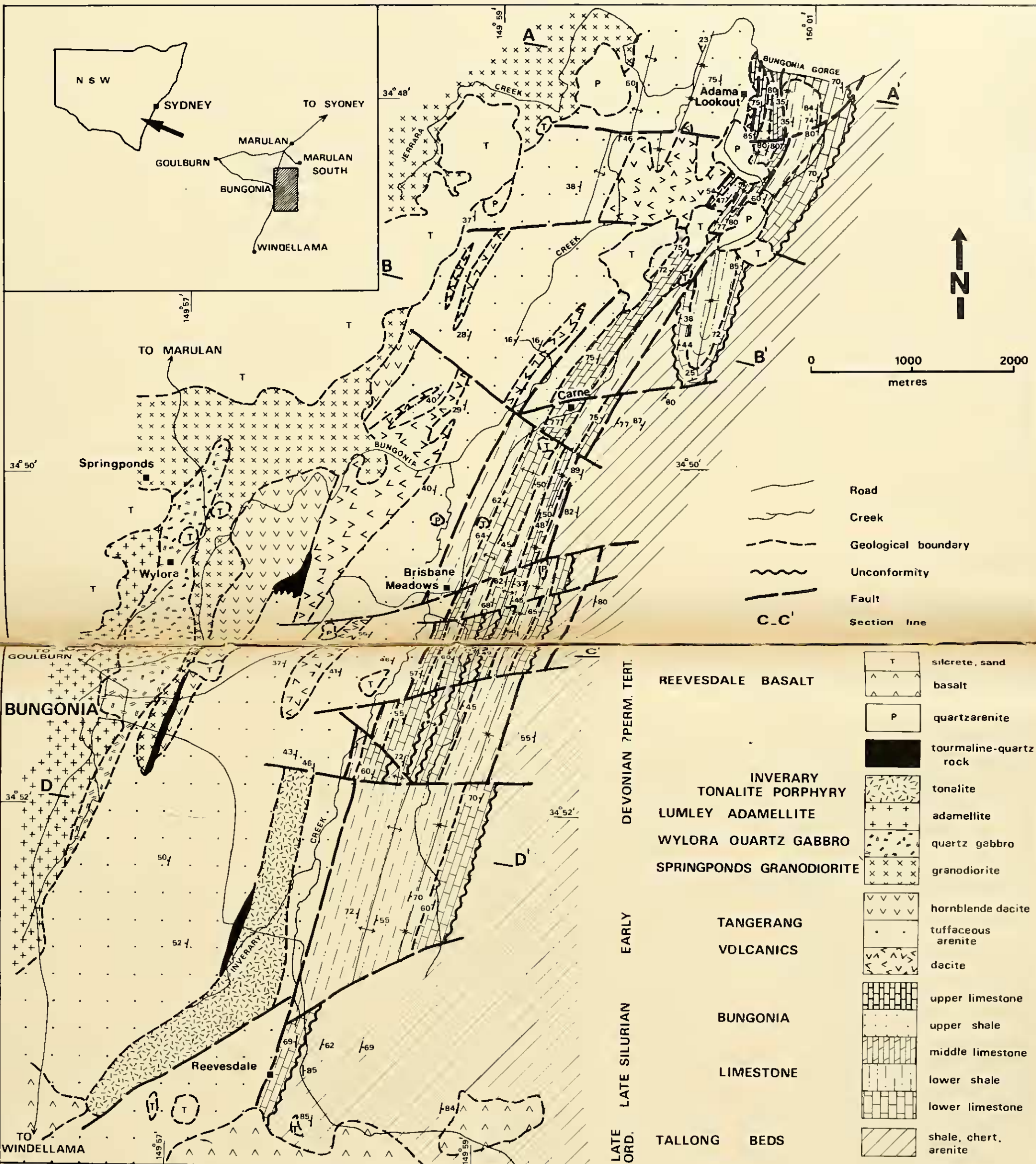

Fig. 1. Geology of the Bungonia area, New South Wales.

TABLE 1

Petrography of the Tallong Beds

Rock Type	Composition	Other Features
Quartz-rich arenite	Fine-grained, poorly to moderately sorted, immature sublitharenite. Quartz (to 80%), feldspar (0-5%), sandstone and chert rock fragments (7%), muscovite (0-5%); minor epidote, amphibole, biotite, chlorite; rare zircon, rutile, tourmaline and iron-titanium oxides. Framework grains subangular to subrounded. Matrix (5-20%) of sericite, clay, quartz and carbonaceous material. Minor quartz cement and secondary chlorite.	Most prominent in northeast. Massive to flat bedded. Symmetrical and asymmetrical ripples. Bouma sequences include erosional base, sole marks, load casts, flame structures, graded beds, ripple cross-beds and small slumps. Arenite interbedded with siltstone and shale in 0.1-1m units. Generally show medium to large scale isoclinal folds.
Carbonaceous shale and slate	Very fine-grained quartz, muscovite, chlorite, clay, pyrite (to 15%) and organic matter (>10%). Reflectivity of graptolites in the range $\bar{R}_o$max 8.35% to 10.01%.	Occur as interbeds in arenite or as massive shale with lenses of chert, siltstone and very fine grained sandstone. Abundant graptolites. Some small isoclinal folds.
Non-carbonaceous siltstone, shale, slate and phyllite	Well sorted siltstone with quartz (75-95%); minor sodic plagioclase, chert, muscovite; rare biotite, pyrite and hematite. Remaining lithologies very fine grained with quartz, sericite and clay. Slate and phyllite have mica and chlorite (to 30%) defining bedding plane cleavage.	Most prominent in south and east. Lithologies interbedded. Tops of Bouma sequences common. Ripple cross-beds. Some chert lenses. Show small and large scale isoclinal folds.
Chert	Microcrystalline quartz; minor sericite, clay; rare graphite and iron-titanium oxides.	Occurs as interbeds in sandstone and shale. Some secondary chert.

1). An axial plane cleavage is weakly to moderately developed. The stratigraphy of the Tallong Beds is poorly resolved because of faulting and isoclinal folding with meridional axes (Fig. 2).

Environment of Deposition. Sandy units in the Tallong Beds typically exhibit Bouma sequences and a variety of sedimentary structures characteristic of deposition from turbidity currents (Table 1). A thick, predominantly graded-bedded sandstone containing only minor argillaceous interbeds crops out in the northeast of the study area and is interpreted as proximal flysch. Sequences comprising thin alternations of sandstone and slate probably represent distal flysch, whereas the extensive, uniformly

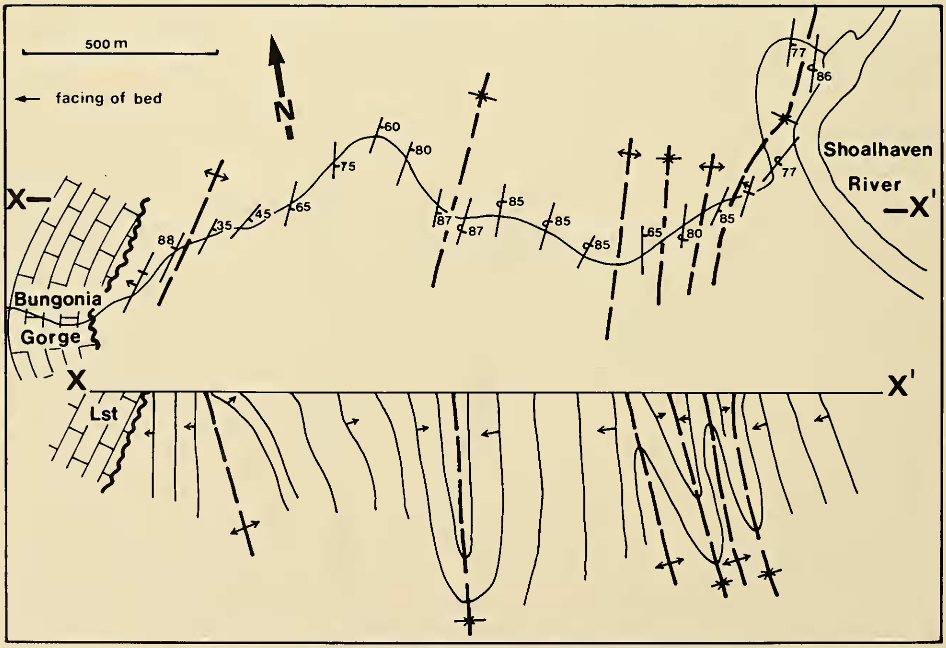

Fig. 2. Structure of Tallong Beds exposed along the lower portion of Bungonia Creek.

thin-bedded, black slate — chert association indicates deposition under moderately quiet water with reducing conditions at the sediment-water interface. A low initial Eh in the black slate facies would favour the preservation of abundant organic matter, including graptolites, and lead to the development of early diagenetic pyrite.

The quartz-rich arenite — slate — chert association conforms to the greywacke — slate suite of Packham (1969) and Unit B of Crook *et al.* (1973) and Scheibner (1973). The source of the sediment was to the south and southwest (current direction to 030° assuming simplest structural interpretation) and may have come from the Canberra-Molong Volcanic Rise and possibly a distant continental mass.

Fauna and Age. The carbonaceous black slates of the Tallong Beds contain graptolite faunas of Late Ordovician age (Sherrard 1949, 1954, 1962; Sherwin, 1972). Ten new Late Ordovician graptolite localities have been recorded in the Bungonia area but most of these have poorly preserved faunas because of surface weathering.

Ordovician-Silurian Boundary

Considerable disagreement has existed over the nature of the boundary between the Tallong Beds and the overlying Bungonia Limestone. A marked angular discordance between the two formations in Bungonia Creek was described as an angular unconformity by Woolnough (1909) and Osborne (1949). However, Naylor (1950) attributed the angular discordance entirely to faulting and suggested that the Bungonia Limestone has a disconformable relationship with the Late Ordovician sequence. Gould (1966), Baker (1971) and Kantsler (1973) have indicated that the isoclinally folded Late Ordovician sequence was deformed at least once prior to the deposition of the Bungonia Limestone and have suggested a faulted contact. Counsell (1973) considered the boundary to be an unconformity and this has been confirmed by the present study.

The base of the Bungonia Limestone between Bungonia Gorge and the southern nose of the plunging syncline northeast of Carne (Fig. 1) is a sharply defined slightly undulating plane which shows no evidence of faulting. This syncline accounts for the very extensive limestone outcrops in the lower part of Bungonia Gorge. Rare clasts of shale from the Tallong Beds occur in the basal 2 m of the limestone just south of Bungonia Creek. Furthermore, the presence of Ordovician graptolitic shale in the core of a small anticline south of Brisbane Meadows is additional evidence for the unconformable nature of the basal contact. In the central part of the area (Fig. 1) the eastern contact of the Bungonia Limestone is faulted.

Bungonia Limestone

The Bungonia Limestone was first described by Woolnough (1909), named by Carne and Jones (1919) and has subsequently been mentioned by several authors. It is subdivided here into five informal units (lower limestone, lower shale, middle limestone, upper shale and upper limestone) which are not of uniform lateral extent. The three limestone units are composed of five interdigitating lithotypes whereas the lower and upper shales are composed of four lithotypes (Table 2).

Lower Limestone. The lower limestone forms the basal unit of the formation except on the western limb of the syncline northeast of Carne where it is underlain by a thin lensoidal fossiliferous sandstone. The lower limestone varies in thickness from 280 m in the north and south, to 90 m northeast of Carne (Fig. 1). Either the original depositional surface was undulating or the transition from limestone to shale was controlled by localized terrigenous sediment input.

TABLE 2

Petrography of the Bungonia Limestone

Unit	Rock Type	Composition	Other features	Fauna
LOWER AND UPPER SHALE	Shale	Illite, chlorite; some sericite, muscovite, biotite, quartz, brown organic matter and fossil fragments. Some shale calcareous or siliceous. Reflectivity of organic matter in the range $\bar{R}_o max$ 2.7% to 6.7%.	Poorly bedded.	Bryozoans, graptolites, trilobites, brachiopods, nautiloids, gastropods and crinoid ossicles.
	Siltstone	Quartz; minor feldspar; rare rock fragments, organic matter, pyrite, zircon, tourmaline and muscovite. Matrix of illite and chlorite. Some siltstone calcareous with fossil fragments.	Poorly to moderately bedded.	Crinoid ossicles.
	Sandstone-sublitharenite	Fine-grained and immature. Subrounded quartz; minor feldspar, chert and lithic fragments, muscovite, biotite, zircon and iron-titanium oxides. Matrix of sericite. Very minor calcite and quartz cement.	Laminated and ripple cross-bedded. Graded bedding.	Crinoid ossicles and corals.
	Chert	Microcrystalline quartz. Some silty chert.	Thin beds.	Crinoid ossicles, corals, brachiopods and bryozoans.
LOWER, MIDDLE AND UPPER LIMESTONE	Biosparudite	Rounded fossil fragments (to 35cm) and some angular to subangular limestone intraclasts (to 20cm). Clasts mainly 5-10cm. Minor detrital quartz and clay. Spar calcite cement.	Massive and biostromes.	Brachipods, crinoid ossicles, corals, stromatoporoids and stromatolites.
	Biosparite	Fossil fragments (approximately 15%) and rounded intraclasts <1mm (to 5%). Poorly washed. Spar calcite cement. No terrigenous material.	5-25cm thick beds interbedded with thin micritic layers.	Brachiopods, corals, crinoid ossicles and bryozoans.
	Biomicrite	Some fossil fragments and pellets. Micrite matrix (30-70%), locally recrystallized to microspar. Minor spar calcite cement. Terrigenous clay locally present.	Beds to 2m. Some fossils abraded. Most abundant lithology (40-70%) in lower and middle limestone.	Brachiopods, corals, stromatoporoids and crinoid ossicles. Some articulated brachiopods with geopetal structures.
	Fossiliferous micrite	Approximately 90-95% micrite. Minor fossil fragments (to 5%).	Thinly bedded, interbedded with biosparite.	Brachiopods, crinoid ossicles and bryozoans.
	Algal micrite	Alternating beds of micrite and carbonaceous micrite. Some clay on bedding planes.	Thin (<0.5mm) lenticular carbonaceous laminae.	
BASAL SAND-STONE	Sandstone-sublitharenite	Medium-grained quartz with some chert, phyllite, fossil fragments and muscovite. Immature to submature. Matrix of sericite, clay and minor calcite.	Poorly bedded.	Crinoid ossicles and brachiopods.

North of Brisbane Meadows the lower limestone contains a prominent basal conglomerate with variable proportions of angular intraclasts and abundant rounded fossil fragments. This basal biosparudite is overlain and replaced laterally by biosparites which show progressively fewer signs of reworking at stratigraphically higher levels. The basal lower limestone is characterized by the presence of large pentamerid brachiopods. Bryozoans, crinoids and corals become more abundant, brachiopods smaller and stromatolites less common from the base to the top of the unit. Also the limestone becomes more micritic, less fossiliferous and darker towards the top. Thinly interbedded micrite and biosparite occur higher in the sequence and pass upwards into wavy laminated algal limestone with thin lenses of marl.

Lower Shale. The thickness of the lower shale varies from 300 m in the northern and southern portions of the study area to 120 m around Carne and Brisbane Meadows (Fig. 1). North of Brisbane Meadows, the lower shale is sparsely fossiliferous (mainly crinoid ossicles). It includes a basal marl overlain by poorly to moderately bedded siltstone and very fine-grained sandstone which passes into thinly bedded siliceous shale. Thin (<20 cm) interbeds of graded sandstone containing angular clasts (up to 5 cm) of shale, limestone and fossil fragments, occur within the siliceous shale near the top of the unit.

The poorly bedded lower shale east and south of Brisbane Meadows contains minor siltstone and chert, and several faunal assemblages including brachiopods, trilobites, graptolites, gastropods, nautiloids and crinoids (Moore, 1976; Carr *et al.*, 1980).

A thin (20 cm) fossiliferous chert occurring 20 to 50 m above the base of the lower shale in the southern part of the area and in the syncline northeast of Carne is a useful marker horizon.

Middle Limestone. The middle limestone is thickest (250 m) around Carne and thins northwards to about 110 m and southwards to 60 m. North of Carne, the unit is composed of massive fossiliferous micrite with some biosparite, marl and shale interbeds. The base of the limestone is characterized by an abundance of corals and bryozoans; the middle by crinoids, bryozoans, corals, brachiopods and stromatoporoids whereas the upper part is dominated by bryozoans and stromatolites. Bioturbation and geopetal structures are present throughout.

South of Carne, the middle limestone has well-developed flaggy bedding with biomicrite and biosparite interbedded with micrite and fossiliferous micrite. Small lenses of biosparudite are also present. Fossils include corals, brachiopods, crinoids and bryozoans. Burrowing is evident in some of the micritic limestone and thinly laminated algal micrite is also present, especially towards the top of the unit.

Upper Shale. The upper shale varies from 50 m to 110 m thick and is only recognized in the northern part of the study area (Fig. 1). The sequence is composed of poorly bedded calcareous, siliceous and sandy shale, siltstone, chert and very fine-grained sandstone. Fossils are generally more common than in the lower shale although their distribution is sporadic. The fauna comprises fenestellid bryozoans, crinoids, brachiopods (including lingulids), bivalves, trilobites and corals.

Upper Limestone. The upper limestone occurs only in the northern part of the district (Fig. 1) and its thickness decreases southwards from 100 m to 50 m. The limestone consists of moderately bedded, sparsely fossiliferous micrite with interbeds of finely laminated algal micrite and lenses of calcareous and siliceous siltstone.

Environment of Deposition. The Bungonia Limestone is a shallow water sequence of biostromal limestone and marine shale deposited on the southern extension of the Capertee Rise. The thickest sequence occurs near Bungonia Gorge. Southwards the formation becomes thinner and more shaly.

In the lower limestone the presence of biosparudite with randomly oriented fragmented fossils indicates wave-induced erosion of a slightly elevated biostrome. A decrease in the amount of reworking in laterally equivalent and stratigraphically higher horizons is indicated by an increase in the abundance of lime-mud. Thick beds of micrite indicate a lack of current activity and imply a rapid rate of precipitation of the carbonate ooze.

The lateral and vertical alternation of high and low energy facies probably represents fluctuations from biostromal shoal to marine lagoonal environments. Restricted circulation in such marine lagoons (Youngs, 1978) leads to poor oxygenation, thereby severely retarding the growth of biostromes, and inducing the deposition of dark micritic limestone.

Wavy-laminated algal limestone with rare domal stromatolites, and micritic limestone rich in stromatoporoids are present in the south. A quiet subtidal environment of deposition is envisaged as the flat-lying algal mats show no sign of desiccation or brecciation (cf. Moore, 1979).

The limestone units pass laterally and vertically into poorly bedded, calcareous and fossiliferous shale. The association of lingulid brachiopods with bryozoans and trilobites in the shale units suggests a shallow water, marine environment. Preservation of graptolites implies a calm environment of deposition. The widespread chert bed may represent a period of very slow deposition on a current swept sea floor. Other evidence of periodic current activity is provided by the presence of thin sandy lenses and concentrations of crinoid ossicles on bedding planes. Graded sandstone beds near the top of the lower shale represent thin proximal turbidite deposits which accumulated in the relatively shallow water depositional basin.

Age. The faunal assemblage in the lower shale indicates that the lower part of the

TABLE 3

Petrography of the Tangerang volcanics

Unit	Rock Type	Composition	Other features
SEDIMENTARY UNITS	Crystal tuff	Coarse- to very coarse-grained (to 5mm), poorly sorted and immature. Very angular to subangular quartz, plagioclase (andesine), iron-titanium oxides; minor chert and volcanic fragments. Chert and chlorite matrix. Secondary sericite, chlorite, clay and calcite.	Poorly to massive bedded. Few thin graded beds. Rare solitary corals and crinoid ossicles.
	Coarse arenite (arkose to feldspathic litharenite)	Very coarse- to medium-grained, very poorly sorted and immature. Angular to subangular quartz (volcanic origin, to 5mm), plagioclase (andesine, 12-47%) fresh and altered to sericite; chlorite, epidote and calcite. Angular intraclasts to 10cm, few granules and pebbles—volcanic fragments (devitrified to chlorite and chert), dacite; few quartz sandstone, quartzite and siltstone. Accessory ilmenite, leucoxene and zircon. Matrix of chert, chlorite, sericite and clay. Cement includes quartz, calcite, secondary amphibole and pyrite.	Dominant lithology in north. Poorly to massive bedded. Some chert breccia. Thin lensoidal conglomerate layers. Rare crinoid ossicles. Calcite cement most abundant in north.
	Fine arenite (quartzarenite, sublitharenite and litharenite)	Poorly to moderately sorted and immature. Very angular to well rounded quartz and minor weathered feldspar (<5%). Rock fragments include siltstone, shale, chert and dacite. Accessory iron-titanium oxides, zircon, tourmaline, anatase and sphene. Matrix of sericite, clay; minor chert and calcite. Cements include quartz and rare calcite especially in the north.	Most abundant lithology in south (approximately 75%). Flat laminated to lenticular beds. Small to medium tabular and trough cross-beds mainly <15cm, few to 1m. Small slumps. Cut and fill structures. Some chert and shale interbeds. Rare bryozoans, corals and crinoid ossicles.
	Chert and shale	Very fine-grained chert, chloritic chert and shale. Shales include detrital quartz, mica and clay.	Thin beds. Massive to poorly bedded, some with undulose laminae. Cherty shale more abundant in south and at top of formation.
EASTERN DACITES	Porphyritic dacite	Phenocrysts of embayed quartz and greenish plagioclase (An_{50-45}). Very fine-grained groundmass of quartz, plagioclase, K-feldspar and minor hornblende, biotite, hypersthene and iron-titanium oxides.	Extensively altered — devitrification of volcanic glass gives abundant chlorite, sericite and kaolinite.
WESTERN HORNBLENDE DACITE	Porphyritic hornblende dacite	Phenocrysts of embayed quartz, hornblende, plagioclase (An_{52-47}) and hypersthene. Groundmass and accessories as above.	As above.

Bungonia Limestone is Late Ludlovian (Carr *et al.,* 1980), which is in agreement with earlier age determinations by Pickett (1967, 1972).

Bungonia Limestone-Tangerang Volcanics Boundary

The boundary between the Bungonia Limestone and the Tangerang volcanics is not exposed in the study area. Although the limestone and volcanics have similar dips, the contact between the units south of Adams Lookout is probably faulted since the basal unit of the Tangerang volcanics overlies several different units of the Bungonia Limestone (Fig. 1). In the Marulan South area the equivalent boundary is considered conformable (Wass and Gould, 1969).

Tangerang Volcanics

The sequence of igneous and volcanogenic sedimentary rocks which overlies the Bungonia Limestone can be equated with the Tangerang volcanics (Wass and Gould, 1969) in the Marulan South region. In the Bungonia area these rocks can be subdivided into (i) the eastern dacites which are interbedded with tuff, tuffaceous to quartzose arenite and shale; and (ii) the western hornblende dacite.

Eastern Dacites. The eastern dacites (Table 3) crop out as elongate lenses parallel to the regional strike in the central and northern parts of the study area.

Sedimentary rocks interbedded with the eastern dacites show a wide range in grain-size and mineralogical composition but characteristically contain angular grains of plagioclase, β-quartz and volcanic rock fragments in a chloritic and cherty matrix. The rocks are texturally and mineralogically immature and the mineralogical composition is strongly grain-size dependent. They grade from very coarse-grained, poorly-sorted crystal tuff and tuffaceous sandstone to well-sorted, fine-grained quartz-rich arenite with minor cherty shale (Table 3, Fig. 3). The arenite tends to become finer and more quartz-rich towards the south.

Western Hornblende Dacite. The hornblende dacite (Table 3) of the Tangerang

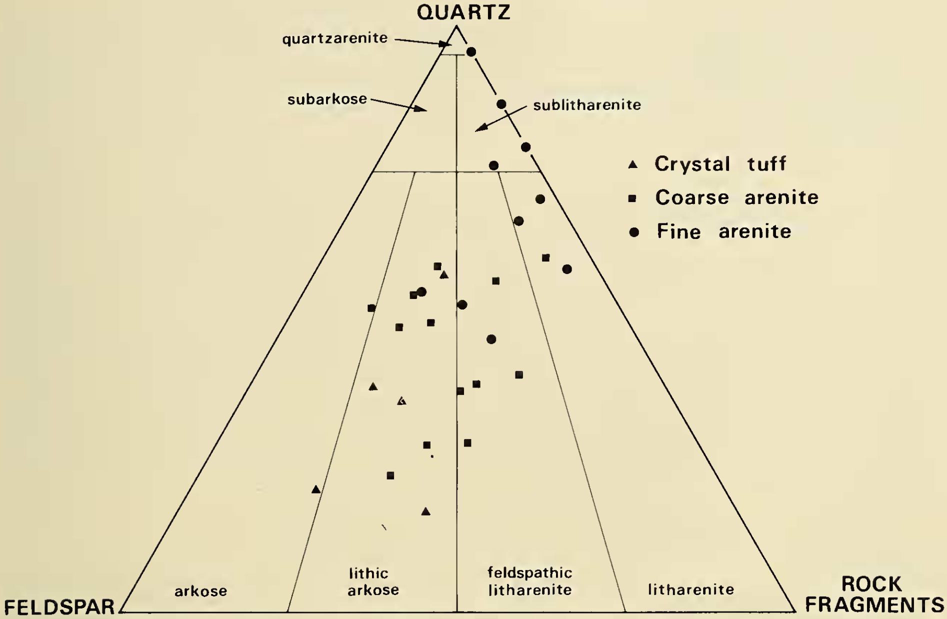

Fig. 3. Mineralogical composition and classification of sedimentary units of the Tangerang volcanics.

volcanics is restricted to the central-western portion of the study area (Fig. 1).

Thickness. Preserved thicknesses of the Tangerang volcanics in the Bungonia area vary from 450 m in the north to 1600 m in the south. The original thickness is indeterminate because the western margin of the formation is an intrusive contact with the Marulan Batholith.

Mode of Emplacement of Igneous Rocks. The dacites and hornblende dacite within the Tangerang volcanics are considered extrusive in origin. The reasons are as follows:

(i) the eastern dacites occur as a series of lensoidal bodies parallel to the regional strike;

(ii) there is no evidence of contact metamorphism along the margins of the igneous rocks;

(iii) possible pillow structures occur at the base of a thin dacite north of Carne;

(iv) microscopic flow-layering is present in some dacites;

(v) β-quartz occurs in all units;

(vi) the dacites are interbedded with tuff and tuffaceous sedimentary units; and

(vii) some of the very fine-grained cherty groundmass of the sedimentary rocks probably originated from devitrification of volcanic glass.

Fauna and Age. Sporadic occurrences of crinoid ossicles, bryozoans and solitary corals have been found in sedimentary units in the lower and middle parts of the Tangerang volcanics but the poorly preserved fossils do not permit an accurate age determination. In the Bungonia area, the Tangerang volcanics are Early Devonian (possibly latest Silurian) in age based on faunas from the Bungonia Limestone and K-Ar dating of the southern part of the Marulan Batholith (Carr *et al.*, 1980).

Environment of Deposition. The Tangerang volcanics represent an accumulation of shallow marine, flat- and cross-bedded arenite interbedded with submarine dacitic lavas and associated pyroclastic rocks. Devitrification of volcanic glass and primary precipitation of silica from marine waters supersaturated by volcanic emanations could account for the high proportion of chert in much of the tuffaceous arenite.

A dacitic volcanic source must have been located to the north of Bungonia since the proportion of dacite and volcanic detritus in the Tangerang volcanics decreases south of the township. At the same time a sedimentary source, probably an exposed block of the Tallong Beds, was contributing fine-grained quartzose detritus to the depositional area.

Marulan Batholith

The Marulan Batholith is a composite body which crops out east and northeast of Goulburn and includes granite, granodiorite, contaminated and hybrid rocks (Woolnough, 1909; Osborne, 1949; Osborne and Lovering, 1953). O'Reilly (1972) considered that the 'hybrid zones' of Osborne and Lovering (1953) correspond to zones of progressive metamorphism of silicic volcanics intruded by magmas forming the batholith complex. Four separate phases of the batholith have been mapped in the Bungonia area (Fig. 1) and K-Ar dating of three of these phases indicates an Early Devonian age of emplacement (Carr *et al.,* 1980).

Springponds Granodiorite (new name). The Springponds Granodiorite crops out extensively in the Bungonia area and is named after the property Springponds (type locality GR701407 — Bungonia 1:25,000 Topographic Sheet).

The rock is holocrystalline, medium- to coarse-grained with a hypidiomorphic granular texture. It contains plagioclase, K-feldspar, quartz, hornblende, biotite and iron-titanium oxides with minor amounts of diopside, hypersthene, chlorite, uralite, prehnite, epidote, apatite, zircon and kaolinite. Plagioclase shows normal and oscillatory zoning from andesine (An_{48}) to oligoclase (An_{22}). The K-feldspar is perthitic and extensively kaolinized.

Wylora Quartz Gabbro (new name). The Wylora Quartz Gabbro has an elongate outcrop to the north and east of Bungonia township and is named after the property Wylora (type locality GR695394 — Bungonia 1: 25,000 Topographic Sheet).

The quartz gabbro is a holocrystalline, medium- to coarse-grained rock with a hypidiomorphic granular texture. Plagioclase, augite, biotite, hornblende, hypersthene, iron-titanium oxides, interstitial quartz and accessory apatite occur in addition to traces of K-feldspar, sericite, carbonate, fibrous amphibole, prehnite and pyrite. The plagioclase shows normal and oscillatory zoning from cores of bytownite (An_{87}) to rims of labradorite (An_{53}).

Lumley Adamellite (new name). The Lumley Adamellite crops out to the south and west of the township of Bungonia and is named after Lumley Creek (type locality GR689385 — Bungonia 1: 25,000 Topographic Sheet).

The adamellite is holocrystalline, medium- to coarse-grained with an allotriomorphic granular texture. Primary minerals are K-feldspar, plagioclase, quartz, biotite, hornblende, apatite, zircon, sphene and iron-titanium oxides. Alteration has produced chlorite, sericite, epidote and prehnite. The K-feldspar is microperthite and the plagioclase is zoned from andesine (An_{35}) to oligoclase (An_{23}).

Inverary Tonalite (new name). Brunker and Offenberg (1968) mapped a number of porphyritic tonalite intrusions on the southeastern portion of the Goulburn 1: 250,000 Geological Sheet. The northernmost tonalite intrusion crops out southeast of Bungonia and is dissected by and named after Inverary Creek (type locality GR711380 — Bungonia 1: 25,000 topographic Sheet).

The eastern contact between the intrusion and the Tangerang volcanics is sharp and dips towards the west at approximately 45° (Fig. 4D). The tonalite is holocrystalline and porphyritic with phenocrysts of plagioclase and subordinate hornblende, biotite and quartz in a fine-grained groundmass of plagioclase, quartz, biotite, hornblende, iron-titanium oxides and minor apatite and zircon. Extensive secondary alteration has produced chlorite, sericite, sphene and leucoxene.

Tourmaline-Quartz Rock. Three separate outcrops of tourmaline-quartz rock have been mapped in the Tangerang volcanics (Fig. 1). Two of the outcrops occur at the margins of intrusions whereas the northern outcrop does not have any obvious field relationship with intrusions. The rocks consist of fine-grained ferrian tourmaline and quartz with minor secondary hematite.

Contact Metamorphism

The Marulan Batholith has produced a narrow (<200 m) aureole within the Tangerang volcanics which is recognized by a slight recrystallization of the dacite groundmass. Contact metamorphism has produced the mineral assemblage albite-epidote-chlorite-actinolite typical of the albite-epidote hornfels facies. At some localities within 10 m of the intrusions the metamorphic grade reaches the hornblende hornfels facies. O'Reilly (1972) has described similar grades of contact metamorphism of silicic volcanic and associated sedimentary rocks around the Marulan Batholith in an area 15 km northwest of Marulan.

Metamorphism of Organic Components

Reflectance measurements on coalified graptolites from the Tallong Beds in Bungonia Creek (Table 1) indicate a metamorphic grade equivalent to the lower greenschist facies (chlorite zone). In contrast, vitrinite-like organic matter from the lower shale of the Bungonia Limestone (Table 2) is considered to represent a regional metamorphic grade equivalent to the upper zeolite facies. The differences in metamorphic grade between the Tallong Beds and the Bungonia Limestone could indicate that the Tallong Beds underwent low grade regional metamorphism prior to the deposition of the Bungonia Limestone. Alternatively the Tallong Beds may have been affected by contact metamorphism from a buried intrusion of the Marulan Batholith, although there is no evidence of this in the topographically equivalent portion of the Bungonia Limestone.

?Permian Sedimentary Rocks

Small outliers of ?Permian quartzarenite unconformably overlie the Bungonia Limestone and Tangerang volcanics and are commonly silicified or ferruginized. Some are cross-stratified (mean foreset azimuth to 340°). The arenite is typically medium- to coarse-grained, poorly sorted and consists of subangular to rounded quartz, lithic chert and rare sericitized K-feldspar, iron-titanium oxides and zircon. Quartz overgrowths and chert cement are present. Some of the arenite contains subrounded to well-rounded pebbles of quartz and quartzite. These outliers are tentatively correlated with the Permian sequence of the Sydney Basin. They are lithologically similar to a fossiliferous Permian outlier at Marulan South described by Wass and Gould (1969).

Reevesdale Basalt (*new name*)

The northernmost flow of the Late Eocene Nerriga Province (Wellman and McDougall, 1974) crops out to the south of Bungonia (Fig. 1) and is named after the property Reevesdale (type locality GR720336 — Bungonia 1: 25,000 Topographic Sheet). Maximum thickness is approximately 8 m but the original thickness and extent are unknown. The rock is an alkali olivine basalt consisting of a fine- to medium-grained assemblage of plagioclase (An_{62-48}), olivine, titaniferous augite, iron-titanium oxides and accessory apatite.

Dykes

Numerous basalt and dolerite dykes occur in the Bungonia area but are too thin to be shown in Fig. 1. The dykes are medium- to fine-grained, have an ophitic texture and consist of plagioclase (An_{65-60}), titaniferous augite, serpentine pseudomorphs after olivine, iron-titanium oxides and minor apatite. The rocks are extensively altered with the development of abundant serpentine, calcite and chlorite. The age of the dykes is uncertain but their emplacement may be related to the extrusion of the Eocene Reevesdale Basalt.

Tertiary Sedimentary Rocks

Poorly-consolidated quartz sandstone and minor conglomerate occur sporadically beneath the Reevesdale Basalt. The age of most other surficial sediments cannot be defined except for the occurrence of *Cinnamomum* spp. leaves (Tertiary) in a ferruginous sandstone southeast of Adams Lookout (Pratt, 1964). Only the major ?Tertiary deposits are shown in Figure 1 and they consist of poorly-consolidated sand, gravel, ferruginous shale and manganiferous grit.

Pedogenic Deposits

(i) Ferruginous surficial deposits, laterite and ferricrete occur as isolated patches over much of the study area. Iron (and manganese) oxides replace the matrix and minerals of the host rock to a variable degree. Ferruginous shale breccias also occur, especially along fault planes.

(ii) Deep red bauxite with a pisolitic texture formed by intense weathering of the Eocene basalt in the Reevesdale area.

(iii) Silcrete occurs on many low hills and ridges throughout the area. It consists of angular to rounded quartz grains with pitted or etched grain boundaries set in a cherty matrix. The silcrete is underlain by a pallid or mottled zone which suggests an origin due to deep weathering (cf. Hutton *et al.,* 1972). The silcrete in this area has been described in detail by Callander (1978).

(iv) Kaolinite deposits of variable quality occur beneath the silcrete.

Structural History

Schematic geological cross-sections which show the major structural features of the Bungonia area are given in Figure 4.

Folding. Two scales of folding have been recognized in the Tallong Beds. Large scale isoclinal folds (F_1) have been mapped in the almost continuous exposures along the lower reaches of Bungonia Creek (Fig. 2). Shale which occurs between the more competent sandstone and chert units shows medium- to small-scale isoclinal folding. These smaller folds are generally not persistent along strike and the fold axes plunge gently (approx. 15°) towards the north-northeast. The shale beds show crenulation cleavage and a marked thickening in many of the fold hinges. Axial planes of the smaller folds have similar orientations to those of the larger folds, suggesting that all these folds were produced concurrently.

Open, gently-plunging concentric folds (F_2) occur in the Bungonia Limestone and the northeastern part of the Tangerang volcanics (Figs 1 and 4). The limestone beds and the Tangerang volcanics act as competent units whereas the interbedded shale is more deformed, shows the development of a weak bedding-plane cleavage and thickening along fold hinges. The meridional F_2 axial planes dip east at approximately 70°. The Tangerang volcanics south of Carne show consistent westerly dips between 35° and 55°.

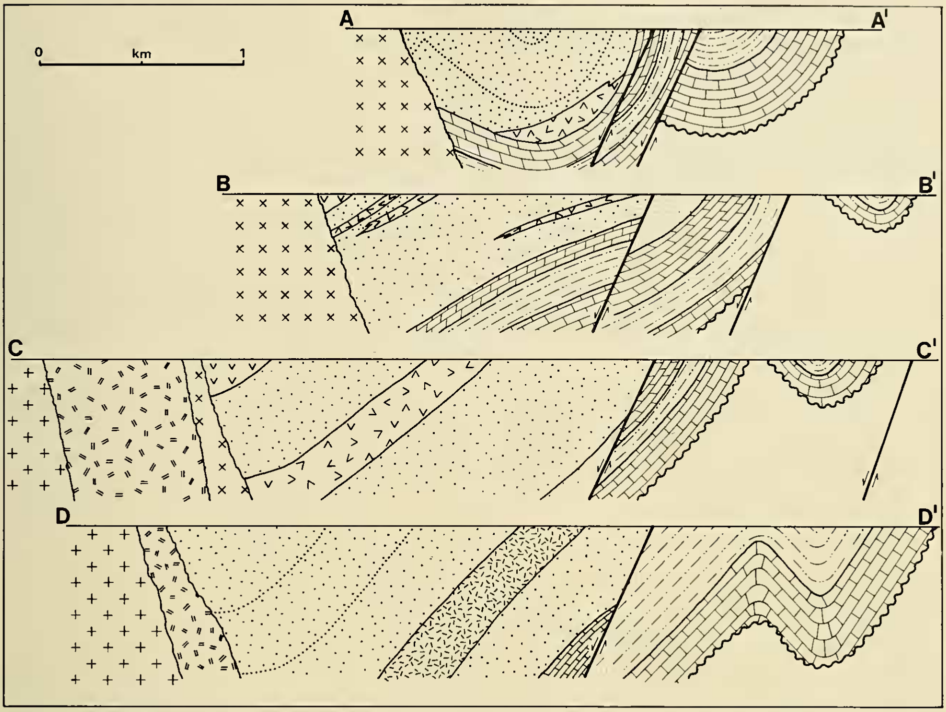

Fig. 4. Idealized geological sections for the Bungonia region. Locations of sections are indicated on Fig. 1.

Between the eastern edge of the Bungonia Limestone and the Shoalhaven River, the mesoscopic F_1 folds in the Tallong Beds are generally symmetrical with almost vertical axial planes, whereas east of the river they become asymmetrical with axial planes dipping at a moderate angle to the east (Baker, 1971). Thus, the Tallong Beds in the study area could represent the eastern limb of a broad F_2 syncline.

Late Devonian strata which crop out about 1 km west of the study area in Lumley Creek and near Oak Valley homestead dip at approximately 15° to 20° towards the west and unconformably overlie more steeply dipping Early Devonian rocks. This post-Devonian tilting could explain the steep easterly dips of the F_2 axial planes.

Faulting. The Bungonia Limestone is cut by two major normal strike faults which both dip 65° to 70° west (Figs 1 and 4). These faults are exposed in Bungonia Gorge as 1 to 3 m wide crush zones. The eastern fault is clearly recognizable from the northern side of Bungonia Gorge by a 30° discordance in dip within the Bungonia Limestone. The strike faults were later cut by a series of oblique faults which show lateral, vertical and slight rotational movement. Only the major faults are indicated in Figure 1.

Discussion

During the Late Ordovician deep marine, quartz-greywacke distal flysch spread throughout the southern Lachlan Geosyncline south and east of Yass (unit B of Crook *et al.,* 1973). The Tallong Beds at Bungonia form a northward extension of this facies and accumulated on the Monaro Slope and Basin near the subduction zone on the eastern edge of the Lachlan Pre-Cratonic Province. The F_1 fold style in the Bungonia area is similar to the isoclinal recumbent folding produced by the Benambran Orogeny in the southeastern part of the Lachlan Fold Belt (Late Bolindian to Late

Llandoverian; Stauffer and Rickard, 1966; Crook *et al.,* 1973). At the time of deposition of the basal part of the Bungonia Limestone (Late Silurian) the axial planes of the F_1 folds probably dipped towards the west at 30°.

The Bungonia region remained deeply submerged after the Benambran Orogeny. Early Silurian graptolitic distal flysch strata (Jerrara Series of Naylor, 1935; 1936; 1950) 6 km west of Bungonia appear to be faulted against the Late Ordovician sequence. The Early Silurian strata show upright isoclinal folding (Naylor, 1936) probably resulting from the Wenlockian Quidongan Orogeny (Crook *et al.,* 1973) but there is no evidence of this fold style at Bungonia. The Quidongan Orogeny encompassed a major period of uplift in the Quidong-Canberra region (Crook *et al.,* 1973) which is extended to the Bungonia area to account for the change from distal flysch facies in the Early Silurian to a shallow marine environment in the Late Silurian. The Quidongan Orogeny also led to the formation of the Capertee Rise and the Hill End Trough by splitting off from the Molong Volcanic Rise (Scheibner, 1973). Deformation and uplift of Late Ordovician (Powell and Fergusson, 1979) and Late Ordovician to Early Silurian (Powell *et al.,* 1976) sequences prior to Late Silurian deposition has also been recognized in the Cookbundoon Syncline 60 km northwest of Bungonia.

The southern part of the Capertee Rise was submerged during the Late Ludlovian and the shallow marine Bungonia Limestone was deposited unconformably on the Tallong Beds. Limestone deposition alternated with periods of greater input of fine-grained clastic detritus and was terminated by eruption of calc-alkaline acid volcanics on the Bungonia portion of the Capertee Volcanic Arch in the earliest Devonian or latest Silurian (Carr *et al.,* 1980). Volcanic activity was presumably related to the high level intrusion of orogenic granitic rocks. Scheibner (1973) implied that these magmas were associated with a zone of secondary subduction. The phase of F_2 folding almost certainly accompanied the east-west compression associated with the intrusion of the southern part of the Marulan Batholith in the Early Devonian and is therefore associated with the Bowning Orogeny. At the close of this phase of folding, the axial planes of the F_1 folds probably would have dipped west at a high angle (about 75°).

Northwest of Bungonia in the Murruin Creek area of the Cookbundoon Syncline, Powell *et al.* (1976, figs 4 and 5) have noted a low angle unconformity between Late Silurian strata and Early to ?Middle Devonian sandstone and conglomerate. Further south in the Taralga area a post-Late Silurian pre-Late Devonian fold episode produced upright open folds (Powell and Fergusson, 1979, fig. 7). The folding in the latter area is similar in style to the phase of F_2 folding at Bungonia and could therefore be related to the Early Devonian Bowning Orogeny rather than a Middle Devonian event as suggested by Powell and Fergusson (1979).

The age of the faulting in the Bungonia area is difficult to ascertain but at least some of the faults are younger than the F_2 folding and may be related to a tensional phase of the Bowning Orogeny. Most of the oblique faults post-date the strike faults.

The effects of the Bowning Orogeny increase in intensity south and west of the Bungonia area towards Wyangala, Breadalbane, Tarago and Bowning (Packham, 1969, 1978). The Ordovician to middle-Early Devonian stratigraphic succession and deformational history of the Tarago area (Felton and Huleatt, 1977; Gilligan *et al.,* 1979) is similar to that of the Bungonia area some 70 km to the northeast although the open fold style produced during the Bowning Orogeny at Tarago has an associated axial plane slaty cleavage.

Cratonization of the Lachlan Fold Belt occurred during the Mid-Devonian Tabberabberan Orogeny (Scheibner, 1973) but there is little or no evidence of this orogenic episode in the Bungonia area. From studies in the northeastern part of the Lachlan Fold Belt, Powell and Edgecombe (1978) concluded that uplift, tilting and erosion occurred during the Middle Devonian but that there was no evidence of an intense orogenic episode beneath the Late Devonian Lambie and Catombal Groups.

The Bungonia region was covered by shallow marine and terrestrial sediments of the Late Devonian Lambian Transitional Province. The folding of these beds must have occurred between the latest Devonian and Middle Permian and is probably related to the Carboniferous Kanimblan Orogeny.

The sequence of deformational events recorded at Bungonia therefore can be related to the widespread orogenic episodes recognized in the southeastern Lachlan Fold Belt (e.g. Packham, 1969, 1978). The intrusion of the Early Devonian Marulan Batholith across the F_2 fold structures in the Late Silurian to earliest Devonian strata precludes the possibility that all the deformation occurred as a single latest Devonian to Early Carboniferous regional deformational phase as suggested by Powell *et al.* (1976).

Remnants of flat-lying Middle Permian (Wass and Gould, 1969) Sydney Basin sedimentary rocks and Cainozoic volcanic rocks, sediments and pedogenic deposits complete the regional history.

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